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ABSTRACT

During the period covered by this contract the major thrust areas of the Columbia Radiation Laboratory were in the fields of quantum optics, energy transfer and relaxation, spectroscopy, the generation and control of electromagnetic radiation, quantum detection and sensing of radiation, and the physical properties of electronic materials. Research supported by the contract led to 79 publications in the Physical Review Letters, Applied Physics Letters, Physics Letters, Optics Communications, the Physical Review, the Journal of Chemical Physics, and other major journals. Nine students received the Ph.D. degree for work performed under this contract.

I. RELAXATION AND ENERGY TRANSFER IN ALKALI METALS

A new diagnostic technique for flames has been developed. The flame is seeded with a small amount of sodium salt and the sodium atoms in the flame are spin polarized by optical pumping. The spin relaxation rates vary substantially across the spatial extent of the flame.

Good agreement has been found between recent calculations of emission and absorption profiles of alkali-noble gas excimers and experimental measurements from this laboratory.

Experimental evidence has been obtained for the existence of potassium polyxenide exciplexes of the form KXe_n , $n = 1, 2, 3, 4$. These exciplexes radiate strongly in the green region of the spectrum.

We have completed the design of an experimental system for time-resolved studies of alkali-noble-gas excimer molecules. The aim of this work is to determine the dominant formation and destruction mechanisms of the higher excited states of these interesting and potentially useful molecules.

Preliminary studies of the spin relaxation rates of sodium in xenon gas have been completed. The aim of these studies is to develop an efficient way to polarize the nucleus of Xe^{129} , a very slowly relaxing species which would be of great interest as a component of nuclear magnetic resonance gyroscopes.

We have discovered a novel spatially propagating wavefront which is generated by laser pumping of an optically thick medium to a state of complete transparency. The wavefront velocity v is related to the number of photons n absorbed per atom by $v = I_0(N_n)^{-1}$, where I_0 is the photon flux and N is the atomic number density.

A new region of infrared absorption has been found for saturated alkali vapors. The absorption shows the analog of the ultraviolet emission continuum of the H_2 molecule. In addition evidence is found for alkali trimers absorbing

in the infrared.

The design of an experiment to measure the magnetic circular dichroism of saturated alkali vapors has been completed. The results of this experiment will be used to assign quantum numbers to several prominent but poorly understood absorption bands in the visible and near ultraviolet region of the spectrum.

We have completed the preliminary design of an experiment to measure the hyperfine structure of the unusually long-lived 5D state of the cesium atom. Because of the very narrow natural width of this state, exceptionally high resolution is possible. We hope to use the results of these measurements to make the first precise determination of the nuclear quadrupole moment of the cesium nucleus.

Optical pumping of Cs vapor using second resonance- D_1 light at 4593 \AA , has been achieved. The percent spin-polarization appears to saturate with dye laser power at levels much lower than 100% and to decrease with Cs temperature. This saturation of polarization, is somewhat reduced by the addition of N_2 gas, but persists even at a N_2 pressure of 200 torr for which no radiation trapping is possible. It appears that spin-exchange between Cs atoms is the mechanism limiting spin polarization at high ($>10^{13} \text{ cm}^{-3}$) Cs densities. Theoretical calculations of the spin polarization, taking into account spin-exchange, were carried out and are in qualitative agreement with the experiment.

The narrow absorption bands of Cs_2 molecules near 700 nm have been identified for the first time as transitions at very large internuclear separations, possibly from the repulsive $^3\Sigma_u$ ground state.

Pulsed dye laser excitation of alkali vapors has been shown to lead to

nearly complete photoionization of the alkali atoms. The local electric fields from the resulting plasma lead to stimulated emission of highly forbidden atomic transitions.

II. RELAXATION AND ENERGY TRANSFER IN SMALL POLYATOMIC MOLECULES

A method has been developed which provides a complete description of the energy and population distributions in a laser pumped, metastable polyatomic molecule. Different temperatures are required for each mode and for the translational/rotational degrees of freedom. Good agreement between calculated and measured distributions has been found for CH_3F . Vibrational energy for this system tends to accumulate preferentially in the ν_3 C-F stretch vibrational mode. As a result, extremely large population inversions are predicted for CH_3F when optically pumped by a CO_2 laser. These results are expected to apply to many polyatomic molecules.

Energy transfer cross sections have been measured for methyl fluoride/rare gas collision events. For the first time in a polyatomic molecule larger than 3 atoms, individual kinetic rate constants for specific intermode energy exchange processes have been obtained. The general qualitative features which describe the variation of rate constants with rare gas atoms are predicted by simple theoretical considerations, but quantitative agreement is seriously lacking.

Intermode collisional energy exchange events coupling the ν_2 , ν_6 , and $\nu_{3,5}$ modes of fluorophosgene (COF_2) have been studied in detail. Approximately 500 gas kinetic collisions are required to transfer population from ν_2 to ν_6 while only 180 collisions are necessary for ν_6 to $\nu_{3,5}$ transfer. The direct coupling between ν_2 and $\nu_{3,5}$ has been found to be weak (> 1500 collisions). The transfer of energy into the translational and rotational degrees of freedom has been found to be noticeably slower than intermode collisional energy exchange.

Energy transfer processes which collisionally couple the vibrational modes of CF_3Cl have been investigated. On the time scale of a laser pulse

width, at high pressures of CF_3Cl , significant energy transfer takes place. No evidence for locking of energy into a single mode has been found for this molecule.

Intermode energy transfer processes have also been investigated in OCS , CH_3COF and $\text{SO}_2/^{18}\text{O}_2$. Rates and cross sections for individual kinetic steps due to collisions have been obtained.

Preliminary measurements of vibrational temperatures have been made in COF_2 which indicate that the ν_1 and ν_2 modes can be made very hot. Multiphoton dissociation of COF_2 using a CO_2 laser has been observed to produce F atoms.

The CO_2 laser driven decomposition of perfluorocyclobutanone has been studied. Time resolved infrared fluorescence from product molecules has been observed, and product yields have been measured. The present experimental evidence suggests that at least some of the products are formed coincident with the laser pulse suggesting multiphoton decomposition of the parent perfluorocyclobutanone.

Time resolved studies of NO_2 fluorescence in the visible region of the spectrum have been undertaken to gain a better understanding of the anomalous radiative lifetimes of this important product of combustion in air.

III. GENERATION AND CONTROL OF RADIATION

We have made the first observations in Na vapor of three new types of echoes: excited-state photon echoes, tri-level echoes, and two-photon echoes. The excited-state photon echo extends the photon echo effect to transitions between states which are both thermally unpopulated. The tri-level echo is a totally new effect peculiar to multilevel (three levels or more) systems. The two-photon echo is the sum-frequency analogue of the Raman (difference-frequency) echo. We have used these new effects to study foreign-gas collisional relaxation of atomic Na S-P and S-D superposition states.

We have made the unprecedented finding that an echo can be generated from the information stored in a single atomic state. This enables echoes to be used to study the effect of collisions on atoms in one state. An echo detection technique which utilizes the relative polarizations of the excitation pulses and the echo has been developed which makes echo effects much easier to observe. Finally the tri-level echo technique (which we recently developed) has been used to perform the first comprehensive study of collisionally-induced relaxation of high Rydberg S and D states in an alkali atom.

Photon echo modulation effects in $\text{Pr}^{3+}:\text{LaF}_3$ have been analyzed in terms of a combined interaction of the nuclear quadrupole interaction and the second order hyperfine interaction. Using the interaction parameters obtained elsewhere, the theoretical echo behavior fits the experimental data successfully. The sign of the electric field gradient at the Pr site inferred from our data is negative.

Two newly developed nitrogen pumped dye lasers are used to generate photon echoes in $\text{LaF}_3:\text{Pr}^{3+}$ at pulse separations as large as 8.0 μsec . Data

analysis yields excited state nuclear quadrupole splittings of 0.73 MHz and 1.12 MHz. Inhomogeneous broadenings associated with these splittings are found to lead to echo modulation damping. We have also observed an unusual dependence of homogeneous relaxation on detuning in the inhomogeneous profile as well as long-lived stimulated photon echoes.

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INDEX TERMS ASSIGNED

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IV. QUANTUM DETECTION AND SENSING OF RADIATION

A heterodyne correlation radiometer for the sensitive detection of radiating species whose Doppler shift is known, but whose presence we wish to affirm has been considered. Such radiation (which may be actively induced) can arise, for example, from remote molecular emitters, impurities and pollutants, trace minerals, chemical agents, or a general multiline source. A radiating sample of the species to be detected is physically made a part of the laboratory receiver, and serves as a kind of frequency-domain template with which the remote radiation is correlated, after heterodyne detection. The system is expected to be especially useful for the detection of sources whose radiated energy is distributed over a large number of lines, with frequencies that are not necessarily known. We have also considered the performance of a conventional optical heterodyne system in estimating the mean intensity of a Gaussian random signal, and shown that it depends on the degeneracy parameter of the signal radiation.

A single-threshold processor has been derived for a wide class of classical binary decision problems involving the likelihood-ratio detection of a signal embedded in noise. The class of problems we considered encompasses the case of multiple independent (but not necessarily identically distributed) observations of a nonnegative (nonpositive) signal, embedded in additive, independent, and noninterfering noise, where the range of the signal and noise is discrete or continuous. We have shown that a comparison of the sum of the observations with a unique threshold comprises optimum processing, if a weak condition on the noise is satisfied, independent of the signal. Examples of noise densities that satisfy and violate our condition were tabulated. The results were applied to a generalized photocounting optical communication system, and it was shown that most components of the system could be incorporated into our model.

We also obtained exact photocounting distributions for a pulse of light whose intensity is exponentially decaying in time, when the underlying photon statistics are Poisson. It was assumed that the starting time for the sampling interval (which is of arbitrary duration) is uniformly distributed. The probability of registering n counts in the fixed time T was shown to be given in terms of the incomplete gamma function for $n \geq 1$ and in terms of the exponential integral for $n = 0$. Simple closed-form expressions were obtained for the count mean and variance. The results are of interest in certain studies involving spontaneous emission, radiation damage in solids, and nuclear counting.

Expressions have been obtained for the mean and variance of the number of events in a fixed sampling time for a nonparalyzable dead-time counter. The input process was assumed to be Poisson with a rate that is a known function of time. Experiments performed with triangularly and sinusoidally modulated laser radiation provide results that are in accord with theory. We have also reported a series of optical experiments that verify the full theoretical photocounting distributions obtained by Diamant and Teich for triangularly and sinusoidally modulated laser radiation. Another series of experiments validates the nonparalyzable-dead-time-modified versions of these formulas obtained by Cantor and Teich. A new expression has been obtained for the paralyzable-dead-time-modified counting distribution for a modulated source.

The detection of a fluctuating signal in the presence of noise has been considered for a doubly-stochastic Poisson counting system that is subject to fixed nonparalyzable detector dead time. The probability of error and channel capacity were examined. A maximum-likelihood estimate of the mean signal level was obtained for a simple image detection system

with a dead-time-perturbed counting array.

Stable, thermally re-cyclable Niobium point-contact Josephson junctions have been fabricated which are suitable for operation in heterodyne detectors (mixers) at millimeter wavelengths. A Josephson mixer at 115 GHz ($2.6 \text{ mm}-\lambda$) has demonstrated an efficiency more than an order of magnitude greater than the best room temperature detectors. A complete receiver is now being constructed.

Efforts to understand the noise properties of a Josephson mixer have led to a digital computer simulation which agrees well with measurements at 115 GHz.

V. PHYSICAL PROPERTIES AND EFFECTS OF ELECTRONIC MATERIALS

Experimental studies have been made of Si MOS devices with ultrathin (10-50 Å) oxide layers fabricated by low-temperature (700°C) dry oxidation. Electrical and optical properties of these devices reveal that photocurrent suppression occurs for oxides ≥ 20 Å in thickness, and that these effects can be removed by appropriate reverse bias. New modes of quantum detection are suggested by these devices and one such mode, a low-voltage photomultiplication, has been demonstrated for a Au-SiO₂-n type Si structure.

A fundamental asymmetry between the tunneling probabilities for electrons and holes has been observed in ultrathin SiO₂ layers (20-30 Å) which is explained in terms of the E-K dispersion relation in the energy gap of the SiO₂. These probabilities have been measured on the same MOS samples using a new experimental technique combining dark characteristics with measurements of photocurrent suppression by the SiO₂ layer.

The physical mechanisms of the breakdown of carrier confinement have been considered using both the thermionic-emission and diffusion models. It has been shown that, for most practical AlGaAs/GaAs DH lasers, the diffusion current is responsible for carrier leakage. The thermionic-emission of minority carriers is important when the confinement barrier or the mobility is very large. The theory presented is also applicable to structures other than the AlGaAs/GaAs laser.

Majority and minority carrier transport in small geometry (2 μm diameter) Pt-GaAs Schottky barriers have been characterized experimentally. Transistor measurements on a matrix of these diodes, lying within approximately a minority carrier diffusion length of one another, indicates that majority-carrier thermionic emission current dominates for large forward

bias ($\geq 0.4V$). At smaller bias recombination in the space-charge region is most important. The minority carrier injection ratio decreases from 10^{-2} to 10^{-5} over the measurable range of voltage 0.5 to 1.0V. The implications for submillimeter detection and mixing using these devices have been considered.

A general theory has been presented to describe the carrier transport across heterojunction interfaces. In matching the boundary conditions at the interface, the conservation of total energy and perpendicular momentum was assumed and the difference of effective masses on two sides of the junction was taken into account. The quantum mechanical transmission coefficient was calculated by a combined numerical and WKB method. Application of this model to an $Al_xGa_{1-x}As$ GaAs N-n heterojunction was performed and gives rise to rectifying characteristics together with non-saturated reverse current. Comparison with the classical thermionic emission model was made to show the significance of tunneling and the effect of quantum mechanical reflection.

An experimental study has been made of the electronic properties of rectifying metal-Ge (n-type) contacts for a range of metals (Au, Cu, Ag, Pb and Ni) and their optoelectronic characteristics under monochromatic illumination for $\lambda = 0.6328 \mu m$. For each metal, very nearly ideal I-V characteristics were obtained with n values from the exponential forward bias region of 1.02 to 1.08 and excellent reverse saturation at $300^\circ K$. The dependence of photoresponse on thickness of various metal electrodes (from 50 \AA to more than 1000 \AA) was observed. ϕ_B 's found from I-V and C-V measurements are in close agreement within $\pm 0.03 \text{ eV}$. The dependence of quantum efficiency (Q.E.) upon metal thickness was measured for all metals and these results exhibit the expected decline in Q.E. with $d \geq 100 \text{ \AA}$. For $d \leq 100 \text{ \AA}$, Q.E. can go as high as 75% at $\lambda = 6328 \text{ \AA}$.

PERSONNEL

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- Irwin Shamah and G. W. Flynn, "Laser Catalized Translational to Vibrational Energy Conversion in $\text{CH}_3\text{F}-\text{O}_2$ Mixtures," J. Chem. Phy., in press.
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- C. M. Wu and E. S. Yang, "Carrier Transport Across Heterojunction Interfaces," Solid St. Electron., in press.

PAPERS BY CRL STAFF MEMBERS PRESENTED AT SCIENTIFIC MEETINGS

April 1, 1977 - March 31, 1979

- H. C. Card, "Physics of MIS-Schottky Barrier Solar Cells," Device Research Conference, Cornell University, Ithaca, New York, June 27-29, 1977.
- H. C. Card and K. K. Ng, "Photocurrent Suppression and Interface State Recombination in MIS-Schottky Barriers," IEEE International Electron Devices Meeting, Washington, D.C., December, 1977.
- H. C. Card, "Physics and Applications of MOS Devices with Ultra-Thin (Tunnelable) Oxides," JSEP Topical Review on Semiconductor I.C.'s, Devices and Materials, Stanford University, August 3-4, 1977.
- H. C. Card, "The Theory of MIS Solar Cells," Gordon Research Conference on Metal-Insulator-Semiconductor Contacts," Kimball Union Academy, Meriden, New Hampshire, August 21-25, 1978.
- K. H. Casleton, "Vibrational Relaxation of the C=O and C-F Stretching Modes in Carbonyl Fluoride," Gordon Conference on Molecular Energy Transfer, Brewster Academy, Wolfeboro, New Hampshire, July 13, 1977.
- E. Y. Chan and H. C. Card, "Optoelectronic Properties of Metal-Ge Schottky Barrier Quantum Detectors," The International Electronic Device Meeting, Washington, D.C., December 4-6, 1978.
- E. Y. Chan, "Infrared Optoelectronic Properties of Metal-Ge Schottky Barriers," Western Electric Research Center, Princeton, New Jersey, March 13, 1979.
- S. M. Curry, "Infrared CW Laser Excitation and Particulate Formation in Cs and Rb Vapor," San Francisco Meeting of the American Physical Society, San Francisco, California, January 25, 1978.
- M. Elbaum and M. C. Teich, "Optimal Condition for Pulsed Heterodyne Detection of Random Signals," Annual Meeting of the Optical Society of America, San Francisco, California, November, 1978.
- A. Flusberg, T. Mossberg, R. Kachru, and S. R. Hartmann, "Multilevel Echo Relaxation Studies in Gaseous Media," Tenth International Quantum Electronics Conference, Atlanta, Georgia, February 1, 1978.
- G. W. Flynn, "Lasers, Energy Transfer, and Vibrational Photochemistry," Illinois Institute of Technology, Symposium on "Lasers in Chemical Dynamics," May 19, 1977.
- G. W. Flynn, "Progress in Vibrational Energy Transfer," Symposium in Honor of E. Bright Wilson, Georgia Institute of Technology, Atlanta, Georgia, May 25, 1977.
- G. W. Flynn, "Mode-to-Mode Energy Transfer: The Vibrational Overhauser Effect," Workshop on Laser Chemistry, Battelle Institute Northwest, Seattle, Washington, August 23, 1977.

- G. W. Flynn, "Intermode Vibrational Energy Transfer in Small Molecules," Symposium on Energy Transfer in Atoms and Molecules, American Physical Society Meeting, Knoxville, Tennessee, December 5, 1977.
- G. W. Flynn, "Intermode Energy Transfer in Small Molecules," Distinguished Speaker Series, University of Utah, Salt Lake City, Utah, April 6, 1978; Gordon Conference on Radiation Chemistry, Holderness School, Plymouth, New Hampshire, July 17, 1978.
- W. Happer, "États Atomique et Moléculaires Couplés a un Continuum; Atomes et Molécules Hautement Excités," Colloque Internationale du CNRS, France, June 13-17, 1977.
- W. Happer, "Long Range Interactions Between CW Self-Focused Laser Beams in an Atomic Vapor," Third International Conference on Laser Spectroscopy, Jackson Hole, Wyoming, July 4-8, 1977.
- S. R. Hartmann, "The Multiphoton Coherent Hanle Effect," Fourth Rochester Conference on Coherence and Quantum Optics, Rochester, New York, June 8-10, 1977.
- S. R. Hartmann, "Superradiance and the Laser," DOD Conference on New Laser Concepts, Durham, North Carolina, September, 1977.
- R. Kachru, A. Flusberg, T. Mossberg, and S. R. Hartmann, "Foreign-gas-Induced Relaxation of the Rydberg S and D States of the Alkalis," APS Meeting, New York, New York, January 29, 1979.
- M. I. Lester, "Vibrational Energy Equilibration in $\text{SO}_2/^{18}\text{O}_2$ Mixtures," APS Meeting, New York, New York, January 31, 1979.
- J. K. McVey, "Energy Transfer in CF_3Cl ," Gordon Research Conference on Molecular Energy Transfer, Brewster Academy, Wolfeboro, New Hampshire, July 13, 1977.
- J. K. McVey, "Vibrational Relaxation Processes in CF_3Cl at Low Pressures," American Chemical Society Conference, Anaheim, California, March 15, 1978.
- G. Moe and W. Happer, "Three and Four-wave Mixing and Photoionization in Cs Vapor," 1978 Annual Meeting of the American Physical Society, San Francisco, California, January 23, 1978; Bull. Am. Phys. Soc. 23, 33 (1978).
- T. Mossberg, "Two-Photon Echoes in Na Vapor," 1978 Annual Meeting of the American Physical Society, San Francisco, California, January 23, 1978; Bull. Am. Phys. Soc. 23, 33 (1978).
- T. Mossberg, A. Flusberg, R. Kachru, and S. R. Hartmann, "Study of the Velocity-Changing Collisions Between Na Atoms and either He or CO," APS Meeting, New York, January 29, 1979.

- P. Panayotatos and H. C. Card, "Separation of the Basic Mechanisms in Optically-Illuminated Metal-Semiconductor Contacts," 36th Annual Device Research Conference, University of California at Santa Barbara, June 26-27, 1978.
- P. Prucnal and M. C. Teich, "Optimum Detection in Optical Communications With a Simple Counting Processor," Annual Meeting of the Optical Society of America, San Francisco, California, November, 1978.
- P. Prucnal and M. C. Teich, "Statistical Properties of Counting Distributions for Intensity-Modulated Radiation," Annual Meeting of the Optical Society of America, San Francisco, California, November, 1978.
- I. Shamah, "Translation and Vibration Energy Distributions in Metastable Laser Pumped Polyatomic Molecules," Poster Session at Gordon Research Conference on Molecular Energy Transfer, Brewster Academy, Wolfeboro, New Hampshire, July 13, 1977.
- R. Sheorey, "Intermode Energy Flow in Laser Pumped CH_3F ," APS Meeting, New York, New York, January 31, 1979.
- A. C. Tam, "Long Range Interaction Between Laser Beams in an Atomic Vapor," Gordon Research Conference (Atomic Physics) Brewster Academy, Wolfeboro, New Hampshire, July 4-8, 1977.
- A. C. Tam, "Plasma Production in Cs Vapor by a Weak CW Laser Beam at 6010 \AA ," Gordon Research Conference (Nonlinear Effects and Lasers), Holderness School, New Hampshire, August 15-19, 1977.
- M. C. Teich, "Information and Error in Photon Counting Optical Communications and Radar Systems," Topical Conference on Informational Aspects of Decision and Control, Joint Services Electronics Program, Harvard University, Cambridge, Massachusetts, May 5, 1977.
- M. C. Teich, "Photon Counting and Energy Detection: The Experiment of Hecht, Shlaer, and Pirenne Revisited," Annual Meeting of the Society for Neuroscience, Anaheim, California, November 7, 1977.
- M. C. Teich, L. Marin, M. E. Breton, G. Vannucci, P. Prucnal, and W. J. McGill, "Quantum Requirements at the Absolute Threshold with Non-Poisson Visual Stimuli," Annual Meeting of the Association for Research in Vision and Ophthalmology (ARVO), Sarasota, Florida, May, 1978.
- M. C. Teich, "Photon Counting," NSF Grantee-User Group in Optical Communication System, Pittsburgh, Pennsylvania, June, 1978.
- M. C. Teich, "Atmospherically Disturbed Photon Counting Optical Communications," International Symposium on Optical Communication and URSI General Assembly, Helsinki, Finland, August, 1978.
- M. C. Teich, P. R. Prucnal, G. Vannucci, M. E. Breton and W. J. McGill, "Non-Poisson Nature of the Effective Noise in the Visual System Near Threshold," Annual Meeting of the Optical Society of America, San Francisco, California, November, 1978.

G. Vannucci and M. C. Teich, "Dead-Time-Modified Photon Statistics and Their Relationship to the Optical Power Spectrum," Annual Meeting of the Optical Society of America, San Francisco, California, November 1978.

C. M. Wu, E. S. Yang, and H. C. Card, "Current Conduction Across Heterojunction Interfaces," Semiconductor Interfaces Specialists Conference, Miami, Florida, November 30-December 2, 1978.

LECTURES

April 1, 1977 - March 31, 1979

- H. C. Card, "Schottky Barrier Optoelectronics," Research Seminar, RCA Labs. David Sarnoff Res. Ctr., Princeton, N. J., May 26, 1977.
- H. C. Card, "Schottky Barriers," Electrical Engineering Seminar, University of Manitoba, January 10, 1978.
- H. C. Card, "Solar Cells, Basic Principles, and Some Recent Research", Department of Physics, Electrical Engineering, and Energy Research Center, Lehigh University, November 15, 1978.
- K. H. Casleton, "Studies of Mode to Mode Vibrational Energy Transfer and Laser Induced Chemistry," Seminar, Ford Motor Company Research Laboratory, Dearborn, Michigan, September 28, 1977; Seminar, Oak Ridge National Laboratory, Oak Ridge, Tennessee, November 2, 1977.
- S. M. Curry, "Excitation Transfer Reactions in Laser-Excited Cesium Vapor," Seminar, University of Connecticut, Storrs, Connecticut, March 6, 1978.
- S. M. Curry, "Laser-Induced Plasma Formation in Cesium Vapor: An Atomic Chain Reaction," Colloquium, University of Arkansas, Fayetteville, Arkansas, March 24, 1978.
- A. Flusberg, "Multi-level Echoes in Na Vapor," Seminar, NRL, Washington, D. C., November 3, 1977.
- A. Flusberg, "Coherent Atomic Transients and Multi-level Echoes," Colloquium, Hebrew University, Jerusalem, Israel, January 3, 1978.
- A. Flusberg, "Tri-level Echoes," Seminar, Ben Gurion University of the Negev, Beersheva, Israel, January 5, 1978.
- A. Flusberg, "Tri-level Echoes: A New Coherent Transient Effect," Seminar, IBM Research Corp., San Jose, California, February 23, 1978.
- G. W. Flynn, "Mode-to-Mode Energy Transfer in Small Polyatomic Molecules," Allied Chemical Company, Morristown, New Jersey, June 6, 1977; Livermore Laboratories, Livermore, California, August 18, 1977; University of Rochester, Rochester, New York, September 21, 1977; Rice University, Houston, Texas, October 7, 1977, Ohio State University, Columbus, Ohio, October 20, 1977; Argonne National Laboratory, Argonne, Illinois, October 21, 1977; University of Iowa, December 1, 1977.
- G. W. Flynn, "Energy Transfer and Chemical Reactivity in Small Molecules," University of North Carolina, Raleigh, North Carolina, January 30, 1978; Amherst College, Amherst, Massachusetts, March 3, 1978; University of Toronto, Toronto, Canada, March 15, 1978; University of Waterloo, Waterloo, Canada, March 16, 1978.

- G. W. Flynn, "Collision Induced Mode to Mode Energy Transfer and Metastability in Laser Pumped Molecules," University of Nevada, Reno, Nevada, April 5, 1978; University of Colorado, Boulder, Colorado, April 10, 1978; Colorado State University, Fort Collins, Colorado, April 11, 1978; University of Chicago, Chicago, Illinois, June 6, 1978; University of North Carolina, Chapel Hill, North Carolina, October 17, 1978; University of California, Berkeley, California, October 24, 1978; California Institute of Technology, Pasadena, California, October 25, 1978; University of Nebraska, Lincoln, Nebraska, March 2, 1979.
- W. Happer, "Laser Snow," Wesleyan University, Middletown, Connecticut, April 7, 1977; Harvard University, Cambridge, Massachusetts, May 23, 1977.
- W. Happer, "Highly Excited Alkali-Noble Gas Excimers," Meudon Observatory, Paris, France, June 10, 1977.
- W. Happer, "Long Range Interactions Between cw Self-Focused Laser Beams in an Atomic Vapor," University of Rochester, Rochester, New York, November 8, 1977; Thomas J. Watson IBM Research Center, Yorktown Heights, New York, November 17, 1977.
- W. Happer, "Attraction and Repulsion of Laser Beams," Department of Physics, University of Illinois, October 12, 1978; Department of Physics, Princeton University, November 9, 1978.
- W. Happer, "Laser Snow," Department of Physics, Texas A & M University, October 19, 1978; Department of Physics, University of Texas at Dallas, February 1, 1979; JILA Colloquium, University of Colorado, March 8, 1979.
- W. Happer, "Laser Photochemistry of Alkali Vapor Hydrogen System," Seminar, Exxon Research Laboratories, December 21, 1978.
- S. R. Hartmann, "Tri-Level Echoes in Atomic Vapors," Seminar, Massachusetts Institute of Technology, Cambridge, Massachusetts, March 2, 1978.
- S. R. Hartmann, "Superradiance," Colloquium, University of Maryland, College Park, Maryland, 1977.
- J. Liran, "Two Photon Near Resonance Scattering From Sodium Vapor," Resonance Seminar, Columbia University, New York, New York, December 15, 1978.
- J. K. McVey, "Energy Transfer and Chemistry in IR-Excited Polyatomics," Seminar, Princeton University, Princeton, New Jersey, March 1, 1978.
- T. Mossberg, "Excited State Echoes," Seminar, Naval Research Laboratory, Washington, D.C., October 17, 1977.
- P. Prucnal, "A New Statistical Discussion Theory Model for Processing in the Visual System," Seminar, Columbia University, New York, New York, February 14, 1979; Bell Laboratories, Holmdel, New Jersey, February 21, 1979; Texas Tech University, Lubbock, Texas, March 5, 1979; Penn State University, State College, Pennsylvania, March 23, 1979.

- P. Prucnal, "Optical Communications and Visual Psychophysics," Seminar, Riverside Research Institute, New York, New York, January, 1979.
- I. Shamah, "Vibrationally Excited States Produced by the Relaxation of Laser Pumped Polyatomic Molecules," Oral Dissertation Seminar, Columbia University, New York, New York, November 16, 1977.
- A. C. Tam, "Forces Between Laser Beams," Seminar, Columbia Radiation Laboratory, New York, New York, June, 1977; Colloquium, Columbia University, New York, New York, November, 1977; Seminar, New York University, New York, New York, December, 1977.
- A. C. Tam, "Display-Magnetometers and Spectrometers," Seminar, Massachusetts Institute of Technology, Cambridge, Massachusetts, October, 1977; Seminar, University of Massachusetts, Amherst, Massachusetts, November, 1977.
- M. C. Teich, "Photon Counting in the Presence of Dead Time," Seminar, New York University, New York, New York, December 19, 1977.
- M. C. Teich, "Imaging, Error, and Information Transmission in Photocounting Optical Radar and Communications Systems," Seminar, Riverside Research Institute, New York, New York, March 8, 1978.
- M. C. Teich, "Dead-Time Effects in the Maintained Discharge of the Cat's Retinal Ganglion Cell," Biomedical Engineering Seminar, Carnegie-Mellon University, Pittsburgh, Pennsylvania, June, 1978.
- M. C. Teich, "The Role of Quantum Optics in Optical Communications," Laboratory of Optics Colloquium, Palacký University, Olomouc, Czechoslovakia, August, 1978.
- E. S. Yang, "Carrier Confinement in Double Heterostructure Injection Lasers," Seminar, Phillips Research Laboratories, Briarcliff Manor, New York, March 2, 1978.

Ph.D. DEGREES AWARDED

April 1, 1977 - March 31, 1979

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A. Glasman

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